United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.446/4
14 August 1985

ENGLISH

Demonstration Workshop on Laboratory and
Pilot Scale Bauxite Processing

Kingston, Jamaica, 28 June - 6 July 1985

CRITICAL PARAMETERS AFFECTING THE MANAGEMENT AND ECONOMICS OF ALUMINA PRODUCTION*

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V.85-29810

THE CHALLENGE

Since most bauxites contain 40 to 50 percent alumina and the alumina is extracted by the 90 year-old Bayer process, one could expect there to be a typical cost of alumina production, but this is not the case. There is no typical cost for alumina production.

The cash cost components for alumina production differ from plant-to-plant. Table I shows a comparative study of a number of existing Alumina plants of different sizes and locations. Bauxite costs range from $20 to $93 per tonne alumina produced, energy from $23 to $81 per tonne alumina, labour from $11 to $50 per tonne, caustic from $3 to $53 per tonne and the other cash costs from $3 to $36 per tonne.

If a plant could be built where all the cost components were at the minimum of the plants studied above, then the cash cost of alumina production would be only $60 per tonne. In contrast, if the plant had all the maximum costs, the alumina would have a cash cost of $313 per tonne. This wide range from $60 to $313 per tonne illustrates the contention that there are no typical costs for alumina production.

Alumina Plants operate to produce a raw material to feed Aluminium Smelters. At the start of 1985 the reported smelter operating capacity in the Western World was at 12.5 MTY

thus creating a demand for some 25 MTY of alumina. Current installed alumina plant capacity is approximately 34 MTY showing a large over supply (Table II). Cash reserves will obviously not allow for the stockpiling of this surplus, therefore, alumina plants will have to cut back on their operating levels, some suffer drastic cut backs and still others shut down completely. What are the critical parameters which will affect the management and economics of alumina production?

WHY DO COSTS DIFFER?

INVESTMENT The investment required for an alumina plant can be between $600 and $1700 per annual tonne of alumina produced, varying with the infrastructure, the plant capacity, location and process flow-sheet. The capital charge, which is the addition to the cash cost required to give a rate of return on the investment depends on the investment; on the discounted cash flow rate of return required; on the taxes paid on profits and on the annual escalation rate. Investments of $1000/annual tonne with 3 percent DCFRR and of $1500/annual tonne with 8 percent DCFRR could require capital charges in the overall range $70 to $190 per tonne of alumina produced. Although we will primarily talk cash costs these non-cash costs should not be forgotten.

BAUXITE Bauxite costs for the selected plants cover a range from $20 to $93 per tonne of alumina produced. The lowest cost is for a mine near to the plant where mining and transportation costs are low and there is no bauxite levy. The highest cost includes a high transportation cost and/or a high levy. Bauxite cost tends to be site specific and beyond noting the importance of proximity of the materials to the Plant site and of taxes, site dependence will not be elaborated.

ENERGY If there is such a thing as a typical alumina plant, it would consume about 12 million BTU per tonne of alumina produced. The type of fuel determines the level of energy cost more than the energy efficiency. The plant, having an energy source of hydroelectricity for steam generation and oil for calcination comes out at $23 per tonne alumina energy cost.

The plant which uses only oil and highly taxed has an energy cost at $81 per tonne of alumina.

LABOUR The labour costs depend on both the labour rates and the workforce required per annual tonne of alumina. Thus, the labour charges are low both for very large plants with high labour rates and the medium sized plants at locations with low labour rates.

Management skill, including the continual training and upgrading of personnel are tools for minimizing labour costs.

Labour in the plants studied showed a range from $11 to $50 per tonne of alumina.

CAUSTIC The caustic cost has a range of $3 to $53 per tonne in the Alumina plants studied. The main variants are price for caustic at the plant site, level of reactive silica in the bauxite and the capacity and efficiency of the soda recovery equipment and rate of reconversion of carbonate to caustic.

OTHER These are cash operating costs other than those mentioned above.

ALUMINA PLANT MANAGEMENT

As the manager of an Alumina plant you will most likely start with an existing plant where the initial decisions of location and size have already been made. Sources of raw materials (Bauxite, caustic, energy, spare parts etc.), markets and customer needs for quality (particle size, impurity levels etc.) already committed.

Even as the wide range of costs shown in Table I illustrates the contention that there are no typical costs for alumina production, it also presents some hope for reducing these costs.

BAUXITE Where mines are operated by the Alumina plants the cost of mining bauxite can be influenced by technological means. However, this is likely to have only negligible effect on the alumina costs short of massive capital charges.

Bauxite cost may also be reduced by improved extraction efficiencies but again the gains although needed are not large.

Where the bauxite costs include significant transportation and/or levy charges these cannot be reduced by technological means.

ENERGY Energy costs for a plant are made up of three components: the cost of generating steam for the process and generating electrical power or purchasing electrical power not generated with process steam and the cost of fuel to calcine alumina. Overall costs can be reduced in two ways - by reducing the amount of energy used, and by reducing the unit cost of energy.

The amount of steam used depends on liquor productivity (the amount of alumina produced by one unit of circulating plant liquor) since higher productivity with the same production rate requires less circulating liquor and hence less energy for heating and pumping liquor.

The other major component of energy cost is the energy used to calcine alumina.

There are three main types of calciners in use: the rotary kiln, the rotary kilns retrofitted to reduce energy consumption and the fluid bed calciner. These are in descending order of energy consumption. For the existing plants with rotary kilns retrofits seem the best choice.

Apart from reducing consumption, energy costs can be reduced by changing to cheaper forms of energy. The cost of energy from coal varies due to a number of factors, but is generally in the range of $1.50 - $2.50/million BTU or about one-half the cost of oil although the advantage over oil is reduced by the capital charge for a new steam generating plant and coal handling facilities.

Energy cost is one of the major variables of alumina production. The fuel type and cost are major factors. However, the cost savings by recovering energy from exit gases of alumina calciners and by improving liquor productivity can be appreciable. In general, an investment in energy management is well rewarded.

CAUSTIC Caustic cost depends on two things - the price paid for caustic soda, and the amount used. Technology can do little about the price. The amount used can be broken down into two components, one of which is caustic consumed by reactive silica in bauxite, which for a given bauxite supply cannot be reduced by plant techniques. The other component of caustic loss comprises losses from the mud washing circuit, physical loss and loss as impurity in product alumina.

SUMMARY

Some specifics for minimizing alumina production costs are summarized as follows:

PLANNING - The Alumina Plants have to be in the right place at the right time, with minimum construction times, followed by operation at rated capacities. Tax incentives and low interest loans ease the capital recovery charges.

RAW MATERIALS - Low cost energy and low cost bauxite are of paramount importance. Mineral benefication may upgrade the bauxite.

TECHNOLOGY - A modular plant design lowers engineering and expansion costs and economies of scale provide an incentive for few process trains.

High liquor productivity reduces investment and operating costs.

Conversion to alternate fuels may lower costs in existing plants.

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ALUMINA PLANT CAPACITIES

COUNTRY	COMPANY/PLANT			CAPACITY MT x 1000 YR
JAMAICA	ALCAN	:	KIRKVINE	550
			EWARTON	550
	JAMALCO	:	HALSE HALL	550-800
	ALPART	:	NAIN	1180
	REVERE	:	MAGGOTTY	200
SURINAME	SURALCO	:	PARANAM	1380
GUYANA	GUYBAU	:	LINDEN	350
AUSTRALIA	ALCOA	:	KWINANA	1400
		:	PINJARRA	2000-2400
		:	WAGERUP	500
	NABALCO	:	GOVE	1000-1100
	Q.A.L.			2400-2700
	WORSLEY			2400-2700

TABLE I

BREAKDOWN OF ALUMINA COSTS

	MINIMUM	MAXIMUM
BAUXITE	20	93
ENERGY	23	81
LABOUR	11	50
CAUSTIC	3	53
OTHER CASH COSTS	3	36
TOTAL CASH COSTS	60	313
CAPITAL CHARGE $1000/AT 4% DCFRR	70	100
$1500/AT 8% DCFRR	120	190

TABLE II

WORLD ALUMINA PRODUCTION

	(MTD x 1000)
INSTALLED CAPATICY	34,000
SMELTER DEMAND	25,000
OVERSUPPLY	9,000

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FLOCCULATION AND SEDIMENTATION OF DISPERSED PARTICULATE SYSTEMS: RECENT DEVELOPMENTS*

Prepared by

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V.85-29811

ABSTRACT

The properties and characteristics of discharged tailings material can be traced, not only to the source material variations, but also to the many complex processes brought to bear, from conditioning, digestion, and separation stages in the extraction of product material. The complex interactions established between the various constituents in the tailings material discharged, can be evaluated in terms of specific suspension volumes -- which express the amount of water held by each specific constituent in the tailings. Furthermore, the subsequent dynamics of the material -- settling, dehydration and crusting -- can be better assessed if the mechanisms which promote interaction between the constituents are better understood. The suspension volume concept provides the first step towards this direction.

INTRODUCTION

The basic compositional constituents for dispersed particulate systems, produced as a result of mineral extraction processes from host rock, can be broadly grouped into 4 groups.

These are:

(a) inorganic solids consisting primarily of mineral particles and amorphous materials,
(b) organics and humic material,
(c) dissolved and undissolved electrolytes, and
(d) micro-organisms.

The general terms used to identify these dispersed particulate systems include: tailings material, slurries, slimes, and sludges. By and large we can consider slurries to contain groups (a) and (c). Slimes are akin to slurries and may contain group (d). Sludges contain groups (a) through (d). Note that there will always be exceptions to the general rule. However, by and large, the basic compositional constituents in slurries, slimes and sludges described above are well established. Note that groups (a) and (c) are common to slurries, slimes and sludges. In many instances, specialized terms are also used: e.g. red mud, phosphatic clays, etc. However, the basic problems pertaining to a general dispersed particulate system remain as common issues, i.e. poor settling characteristics of the slurries and high containment requirements. Figures 1 and 2 demonstrate the problem at hand. The idealization shown in Figure 2 is meant to portray the commonly found stagnant zone where the solids concentration for many slurries appear to hover -- between 30 to 50% solids concentration. This idealized profile is thought to be more representative of Section III in Figure 1, where shoreline discharge of tailings occurs in practice.

STABILITY OF SUSPENDED MATERIAL

In the context of the present discussion on dispersed particulate systems, the presence of groups (a) and (c) are necessary and sufficient conditions for development of the

dispersion stability of suspensions. The addition of groups (b) and (d) serve to both reinforce the dispersion stability of the suspended solids and to alter the complex interactions occurring within the suspension. Common experience with tailings waste containment ponds testify to the problem of reluctant gravitational settling of the suspended solids in the ponds, e.g. Yong et al, (1983), Bureau of Mines, (1975). Since all these waste discharge tails are suspensions, the general term SUSPENSION will be used whenever convenient - to facilitate discussion.

At least three mechanisms can be postulated as being contributing mechanisms for the dispersion stability of suspensions consisting of surface active solids, such as those found in SUSPENSIONS. These are: (1) mutual repulsion of solids due to high zeta potential, (2) adsorption or coating of amorphous material (small lyophilic colloid) on a large electronegative colloid; [the affinity of amorphous material for water exceeds the net attraction of the van der Waals forces], and (3) steric hindrance due to adsorption of an oriented non-ionic organic molecular layer.

In a suspension containing various kinds of constituent solids, we expect all three mechanisms to be present - with differing degrees of influence - in the promotion of the dispersion stability of the suspension. It would be correct to note that it is indeed likely that other mechanisms may exist as complex variants of the above three mechanisms. However, these have yet to be fully identified and documented.

Flocculation and Coagulation

Since solids-liquid self-weight separation will involve processes which have been identified or defined as flocculation and coagulation, it is necessary to define the these terms. The

terms "FLOCCULATION" and "COAGULATION" have often been misused interchangeably - even though each identifies a separate resultant interaction process.

FLOCCULATION as defined by La Mer, is the destabilization of suspensions with the use of natural or synthetic polymers which absorb onto the particles in the suspensions, thus forming bridges between particles and causing aggregation or agglomeration of large assemblies of particles. These agglomerates can only be dispersed into smaller particle groups through the use of mechanical or physical disruptive shear forces.

COAGULATION refers to the destabilization of suspensions by a reduction of the electrostatic repulsive forces, thus allowing the van der Waals attraction forces to cause particle aggregation. The aggregate groups formed can be reversibly dispersed only if secondary bonding, such as cementation bonding between particles, does not occur as a result of biological-/chemical reactions in the ageing period.

The term FLOCS has been used very loosely to describe the agglomeration of particles resulting from the "flocculation" process. This is obviously incorrect since flocs can also be formed through coagulation. FLOCS refers to the grouping (agglomeration, aggregation or clustering) of particles in a manner such that the particles are arranged in a "card-house" structure, i.e. the particles are arranged in an edge-to-edge and edge-to-face configuration. The production of flocs can occur through flocculation or coagulation processes. HOWEVER, it is important to distinguish between flocculation-generated-flocs and coagulation-generated-flocs since the STABILITY OF THE FLOCS will be different. As noted above in the definition of flocculation and coagulation, the flocs generated through coagulation can be reversibly dispersed whilst the flocs developed through flocculation will require mechanical or physical energy input to

destabilize the flocs. It would indeed be simpler to use different terms for the two kinds of flocs. However, common usage of the term in the context of a "card-house" structure permits us to continue usage of the term SO LONG AS we pay particular attention to source mechanisms for the generation of the flocs.

In suspensions (i.e. dispersed particulate systems) consisting of lyophobic colloids, such as slimes, slurries, sludges, red muds, phosphatic clays, etc, it is recognized that their stability depends on the characteristics of particle interaction. The quantitative theory of stability of lyphobic colloids, identified as the DLVO theory (after Derjaguin, Landau, Verwey and Overbeek), which constructs its analytical model on the basis of (a) electrostatic repulsive forces due to interpenetration of the diffuse ionic layers, and (b) van der Waals attraction forces, provides us with a basis for calculation of the energies of interaction between the suspended solids.

Net repulsion occurs between particles (colloids) when double layer repulsion overwhelms van der Waals attraction. The presence of potential determining anions such as bicarbonates, carbonates, hydroxides, phosphates, etc. in the fluid phase, all contribute to the enhancement of net repulsion.

When attractive forces dominate, the system becomes unstable and coagulation occurs. At least two factors are important in the coagulation process: (a) Brownian motion of the constituents particles, and (b) particle interaction. In a system where the repulsive forces are vanishingly small and can be neglected, Brownian collision between particles will lead to agglomeration or aggregation of the particles - thus leading to the production of floc units. Note however that not every collision will result in aggregation. For two different systems, given the same collision frequency, the effectiveness of

aggregation upon collision depends on the properties of the particle surfaces. Under such circumstances, this kind of phenomenom is identified as "slow coagulation".

When the rate of aggregation upon collision does not depend on the properties of surfaces, and is conditioned only by the collision frequency, the process can be identified as "fast coagulation" . The process of coagulation which is caused by the addition of electrolytes, demonstrates the role of the electric state of the interface in the following fashion: (a) coagulation is induced by the ions of charge opposite to that of the particles, (b) similar values of zeta potential will yield correspondingly similar rates of coagulation, and (c) the valency of the ion involved is influential in the determination of coagulation power.

In clay mineral suspensions, the zeta potential at any given clay:water ratio depends on the concentration of electrolyte in the suspension. The mono-molecular layer of the electrolyte on the clay surface is formed at a particular concentration. Yong and Sethi (1977) have shown that a strong relationship exists between the dispersion stability (of the suspension) and the zeta potential of the system, (Table 1).

Table 1 - Dispersion stability of clays and zeta potential

Stability characteristics	ave. zeta potential, mv.
1. Maximum agglomeration and precipitation	+3 to 0
2. Excellent agglomeration and precipitation	-1 to -4
3. Fair agglomeration and precipitation	-5 to -10
4. Threshold of agglomeration	-11 to -20
5. Plateau of slight stability (few domains)	-21 to -30
6. Moderate stability (no domains)	-31 to -40
7. Good stability, i.e. stable suspension	-41 to -50
8. Very good stability	-51 to -60
9. Excellent stability	-61 to -80
10. Maximum stability	-81 to -100

In the ongoing study of the dispersion stability of clay slimes generated from the spearation processes of weathered soil for extraction of coarse aggregate, (in Singapore), the zeta potential of the samples obtained in the stagnant zone show values ranging from -35 to -57 mv. These values, which fit into categories 7 and 8 in Table 1 (good to very good stable suspensions), confirm visual and experimental experience with the recalcitrant settling characteristics of these slimes, (solids concentration of about 37%).

Dispersions of lyophobic colloids (surface active solids) in suspensions are stable due to the presence of strong mutual repulsive forces. Agglomeration or flocculation can be achieved many ways:

1. Through lowering of the zeta potential of the system to zero with the use of a strong cationic electrolyte.
2. Through the use of a strong cationic electroylyte in conjunction with an appropriate alkali. Optimum pH is required.
3. By adding a reagent which results in the formation of an insoluble matrix which engulfs and binds the water in the system. Subsequent removal of the water may be accomplished through such methods as consolidation or electro-osmosis, etc.
4. Agglomeration through the addition of sufficient cationic polyelectrolytes and with recovery of the water through filtration or centrifugation.
5. Agglomeration with long chain or branched-chain anionic polyelectrolytes.
6. Agglomeration with non-ionic long chain or branched-chain polymers.

In suspensions with clay minerals and other soil constituents, the protective coating of amorphous material on clay surfaces may result in strong repulsion between particles, thus rendering stable dispersion conditions. By and large, we note that the amorphous material is composed of oxides of silica and oxides and hydrous-oxides of alumina, and iron. Amorphous materials with high net negative charge and high SiO_2/Fe_2O_3 ratios are generally obtained through chemisorption of silica on ferric hydroxide. Experience has shown that they have a strong affinity with water, and that their properties change on drying. Recent studies in our laboratories show that amorphous materials tend to coat the primary minerals, and to a much lesser extent, the clay minerals. Note that a positively charged amorphous iron-silicate-hydroxide can also be obtained under different environmental conditions. Such a condition for example would be when silanol groups of polysilicic acid react with basic metal groups.

Non-ionic organic molecules are not adsorbed in measureable amounts from aqueous solutions unless there are more than six carbon atoms in the molecule. However, in a non-aqueous environment, their vapours are adsorbed in lesser amounts. Most of the work done in this kind of problem has been in regard to hydroxylic compounds which are adsorbed by hydrogen bonding of polar active groups to oxygen rich clay surfaces. Multiple dispersion forces associated with the many surfaces, contacts per molecule, and the entropy factor are the most important factors contributing to the adsorption of these large molecules. Other important considerations are configuration, moleculer weight and chain length of the organic molecules.

SETTLING/SEDIMENTATION PROCESS

A way in which one can describe the solids-liquid self-weight separation process is to study the settling/sedimentation and consolidation process. This is performed by tracing the "life" or status of a typical representative solid, beginning with its initial state. When discharged, and after formation of a beach, the solids in the slurry in Section III in Figure 1, will settle in a fashion more or less controlled by either gravitational forces or by interactive forces dictated by brownian collision, or by surface-active relationships. The settling process in Section II, Figure 1, is also driven by forces associated with the discharge procedure. Turning our attention to Section III, it is expected that since the concentration of solids concentration in this region (shown as the top two layers in Figure 2) is not sufficient to account for proximal hindrances, one might apply lessons from gas dynamics and seek to promote analyses of suspension stability using binary collision theory, such as that reported by Yong and Wagh, (1985). When surface active forces begin to overpower simple brownian motion, calculations of the settling rate of the suspended solids

must be performed with full accounting for the energies of interaction between solids. The ideal theories, e.g. DLVO, of particle interaction can be invoked to provide one with a sense of the dispersion stability of the suspension.

When settling of a representative solid progresses to the stage where neighbouring solids begin to interfere, the tediously slow settling performance of the solids is apparently hindered not only by the physical interferences of neighbouring solids, but also by interactions controlled by surface active relationships. Because the settling process of suspended solids is a continuous process, the separation between various mechanisms which begin to fully dominate settling characteristics will never be easily defined. At some point, the hindered settling performance will lead to the development of effective stresses, i.e. pore water pressures will be developed. At this time, large strain consolidation modelling can be satisfactorily can be performed -- as shown by Yong et al, (1984) and Yong and Ludwig (1985).

THE CONCEPT OF SUSPENSION VOLUMES

The dispersion stability of the solids suspension, which is indicative of the degree to which the solids remain in suspension, is a direct result of the water-holding capability of the solids. From concepts of diffuse-double layer interaction, it is known that the maximum amount (volume) of water held by each solid or floc is obtained when the counter-balancing ions in the surrounding fluid neutralize the surface charge requirements of the active solid or floc. When two or more solids/flocs interact, this situation is characterized by a zero midplane potential. This can be pictorially represented by the single particle shown in Figure 3, where the counter-ions are shown surrounding a charged plate, and in Figure 4, where the water shell equivalent is depicted. The thickness of this shell, or

the volume of water, can be computed from theoretical considerations using the DLVO model (Yong, 1984). When two or more solids/flocs interact, this situation is characterized by a zero midplane potential -- as seen in Figure 5 where an ideal three-particle parallel arrangement is shown. The amount of water held in this system can be defined as the equilibrium suspension volumem, specific to the solid under consideration and for a zero midplane potential situation. The term "equilibrium suspension volume" thus implicitly denotes a zero osmotic pressure condition. Whilst energy-separation distance calculations will give the most likely equilibrium interparticle spacing and void ratio of the system, representative of the zero osmotic pressure condition, it must be recognized that real slurry systems depart from idealization due to: (a) floc formations, (b) mixed aggregative systems, and (c) presence of other kinds of constituents.

In recognition of the real system, one can approach the calculation of equilibrium water volumes associated with the specific constituents by considering the following thesis: If each solid, or floc "holds" onto a specific volume of water as its "equilibrium" shell of water (defined as the specific suspension volume), consistent with the balance of internal and external energies, the total stable dispersed state of the suspended solids at a particular depth in the containment pond, will show that the total volume of water retained in a representative unit volume would be equal to the sum of the specific suspension volumes, i.e. equal to the sum of the volumes of equilibrium water held by the individual component solids. A simple pictorial representation of this thesis is shown in Figure 6. The various "starbursts" and crossed-circles shown in the Figure are meant to represent the constituents with their equilibrium suspension water volumes. Obviously, the other spaces not shown with constituents will also contain other specific suspension volumes. Yong and Sethi (1978) have shown

from controlled laboratory experiments with mono-mineralic clay suspensions, that the measured equilibrium suspension volume of water associated with specific minerals at zero osmotic pressure, (Table 2), show good correspondence with those computed using the theoretical interaction model, - provided that the theoretical calculations account for the presence of the potential determining anions. The extreme right hand column of Table 2, shows the experimental methods used for determination of the specific suspension volumes. The use of measured suspension volumes in calculating field values of pond suspension volumes, releases one from prior assumptions concerning floc formation or preferred orientations, and will account for suspension fluid chemistry if the same chemistry is used in the experimental tests.

It is useful to note that for suspensions under measurable solids self-weight and even under external stressing conditions, the concept of suspension volumes can be readily applied. If the stresses are calculable, the internal stresses generated between particles -- as interparticle forces or energies of interaction -- can be calculated by considerations of balance of internal and external energies. The equilibrium stress balance situation (between external and internal) will produce equivalent suspension volumes for individual constituents, and can be expressed as "stress-equilibrium suspension volumes". This aspect of the suspension volume concept is particular useful in considerations of large-strain consolidation. Taken to its other end of the spectrum, i.e. in natural soils, the soil-water energy characteristic is a particular application of this concept.

In the following example, taken from Yong (1984), the suspension volumes reported in Table 2 have been used to calculate the "expected" solids concentration in a tin mining slime pond. The constituents in the slime, and their

proportions, which were determined in laboratory analyses, are reported in the first column. The second column shows the measured suspension volumes associated with each type of mineral, (from Table 2), and the third column shows the volume of water associated with each constituent in a 100 gram sample.

Mineral	Suspension Volume, cc/gram (from Table 2)	Specific Volume in Sample, cc/100 gms.
kaolinite - 45%	1.3	58.5
mica - 10%	3.0	30.0
gibbsite - 2%	1.0	2.0
quartz - 40%	0.14	5.6
other - 3%	0.15	0.45
Total = 100% (or 100 grams of solids)		96.55

Hence, weight of water = 96.55 grams.

Total weight = (100 gms. solids) + (96.55 gms. water)
= 196.55 gms.

Computed solids concentration = 100/196.55 = 50.8%
Measured solids concentration = 52%

The comparison between measured and computed solids concentration appears to agree very closely. Table 3, (from Yong, 1984) shows the comparison between "predicted" and measured solids concentration values for various types of waste slurry containment ponds studied. Since the "fine-tuning" of the concept was performed and calibrated with the tar sand sludge ponds, it is not surprising that the agreement between "predicted" and measured values is indeed excellent. However, application to other types of ponds shows clearly that the suspension volume concept is not only viable, but applicable.

Table 2 - Suspension volume for various minerals and method of their determination

Sample No.	Mineral	Suspension Volume (cc/g)	Void Ratio	Specific Gravity	Method of Determination
1	Kaolinite	1.3	3.44	2.65	Settling of pure kaolinite in $NaHCO_3$ for 18 months.
2	Illite	3.1	8.15	2.65	Settling of kaolinite: illite (40:60) in $NaHCO_3$ for 18 months.
3	Montmorillonite	21.5	57.0	2.65	Settling of Na-montmorillonite for 36 months.
4	Amorphous Fe_2O_3	20.5	82.0	4.00	Settling of Fe_2O_3+ kaolinite: illite in $NaHCO_3$ for 18 months, containing 4.5% Fe_2O_3.
5	Gibbsite	1.0	2.65	2.65	Estimated from kaolinite experiments.
6	Mica	3.0	7.95	2.65	Estimated from illite experiments.
7	Quartz	0.14	0.37	2.65	Estimated from Theory of Mixtures.
8	Others*	0.42	1.12	2.65	Assumed.

*Includes feldspar, calcite, ankerite, siderite and pyrite.

Table 3 - Comparison of theoretically computed and measured solids concentration (S.C.) for samples studied

Source	Theoretical S.C. %	Measured S.C. %	Theo. S.C. / Meas. S.C. %
Phosphatic Slime	13.4	14	0.96
Aggregate Slime	10.5	14.3	0.71
Tin Mining Slime	50.8	52	0.98
Clay Coating Slurry	51.8	52.7	0.93
Beneficiation Slurry	9.1	8.7	1.05
Tar Sands Sludge	42.2	41.9	1.01
Bauxite Red Mud	Not computed	20-40	
Soil-Organic Slime	Not computed	2-19	

It is necessary to note that both the theoretically computed and measured values must be considered as "average representative" values since: (a) the method used for determination of the proportion of various minerals from x-ray diffractograms, (b) sampling procedures, (c) quality of samples and how well they represent the actual conditions of the material in the ponds, are significant considerations.

PROCESSING AND SLIME/SLUDGE PROPERTIES

The connection between processing parameters and procedures, and properties, characteristics, and subsequent behaviour of the discharged slime/sludge (tailings) has not been generally established. It seems highly likely that a definite link between two must exist -- since processing, separation, and extraction procedures require that the source material be thermally, physically, and chemically manipulated. In a simplistic way, we presume that mechanical/physical actions, additives and water/heat added at the conditioning and digestion stages, to facilitate processing, will result in transformation and alterations in the constituents which "are left behind" as material for discharge. The somewhat counter-opposing additive functions at the digestion and separation stages, can only add to the complex chemistry of interaction between constituents in the final tailings discharge material. In simple terms, the additives and actions provided in the digestion stage serve to provide a certain degree of dispersion of the fines, to facilitate processing. At the separation stage, one tries to settle the suspended solids quickly and efficiently, and to provide for a high quality liquor or froth -- to yield efficient extraction of the product material. The sediment discharge in the separation stage should be as compact as possible, (and yet demonstrate good dewatering capability), in order that no undue loss of liquor or froth occurs in the sediment.

The result of all the above actions can only serve to influence the developed suspension volumes of the individual constituents, and the overall suspension volume. It is not immediately clear that the dispersion stability of the suspension is not tied intimately with all the intricate processes which begin at the conditioning stage. Furthermore, subsequent tailings discharge performance will also be affected, e.g. settling, dewatering, drying and dehydration, crusting, bonding and irreversibility of bond formation, stability of crusts or dehydration layer, stability of sedimented/consolidated layers, dust formation, etc. Since all the properties and behaviour of the material are derived from interactions between the constituents, and since these can be categorized by the specific suspension volumes, the consideration developed in the earlier part of this paper, concerning suspension volumes becomes significant.

CONCLUDING REMARKS

The status of tailings in a containment pond can be traced to the complex processes brought to bear, from conditioning through digestion, and through separation processes. The complex interactions established between the various constituents in the tailings material discharged can be evaluated in terms of the specific suspension volumes -- which expresses the amount of water held by each specific constituent. The ability to release the water in the suspension volumes constitutes the central issue, and can be better assessed if the mechanisms are more clearly understood. The concept of suspension volumes is the step towards this end.

ACKNOWLEDGEMENTS

This study constitutes part of the general study on Stablity and Settling of Suspended Fines, supported by the

Natural Sciences and Engineering Research Council of Canada. Application to specific waste tailings ponds has been supported by the International Development Research Centre, Canada. The input provided by the various researchers in the Geotechnical Research Centre is also acknowl edged.

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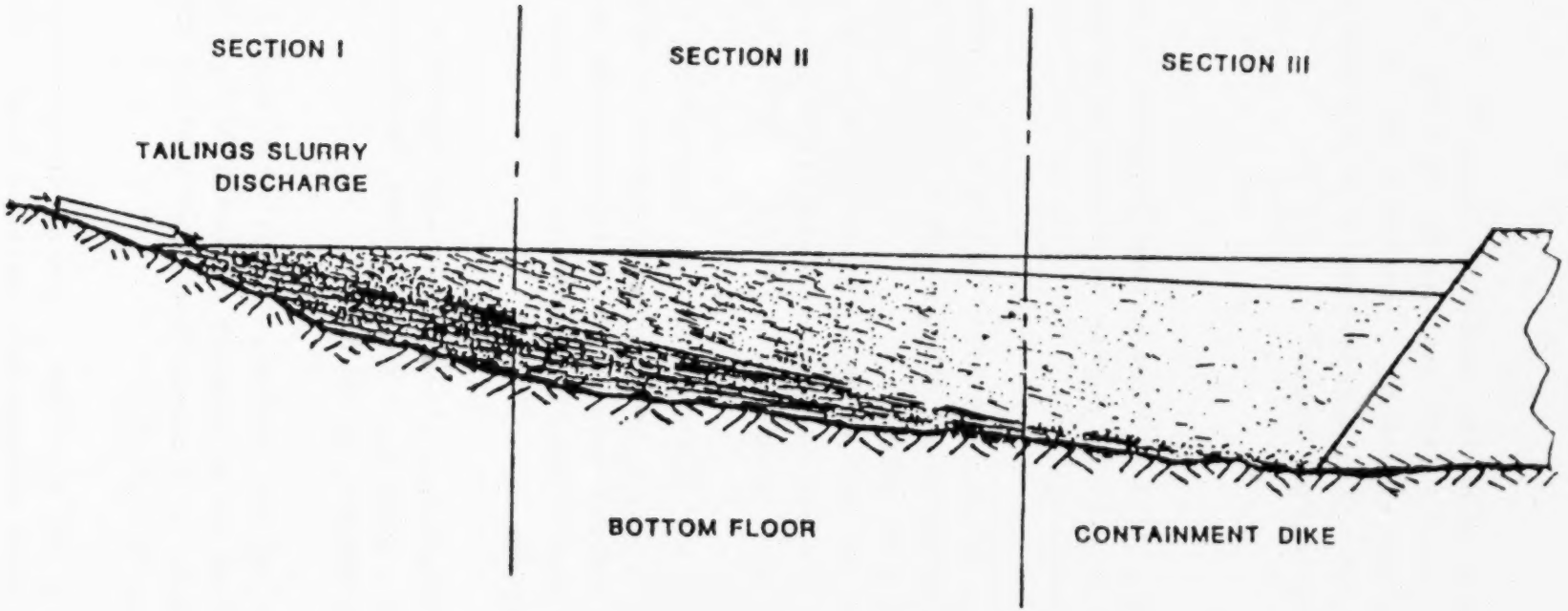


Fig. 1. Schematic view of general waste tailings discharge.

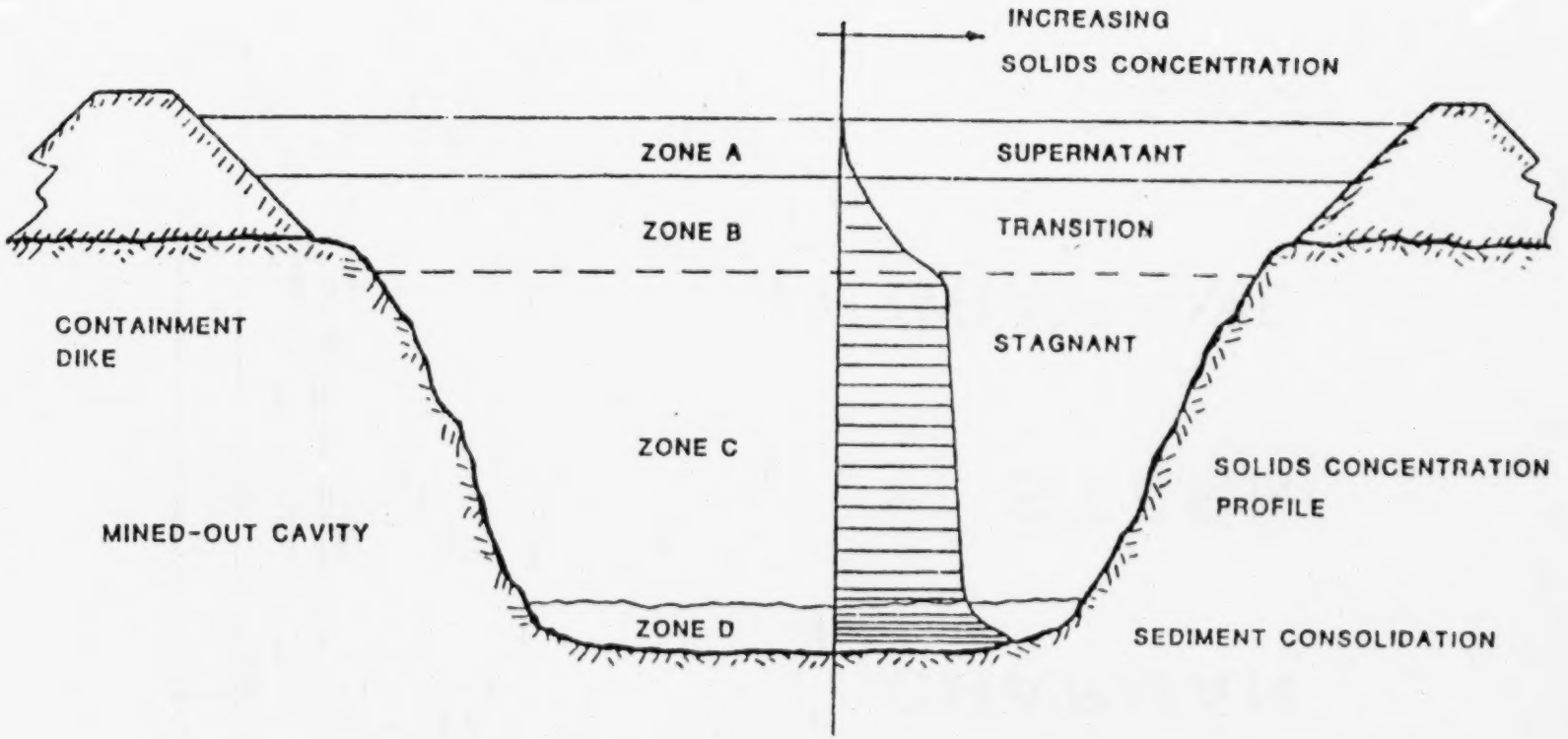


Fig. 2. Idealized schematic of settling pond.

Fig. 3. Counter-balancing ions and charged plates. Note that names refer to analytical models.

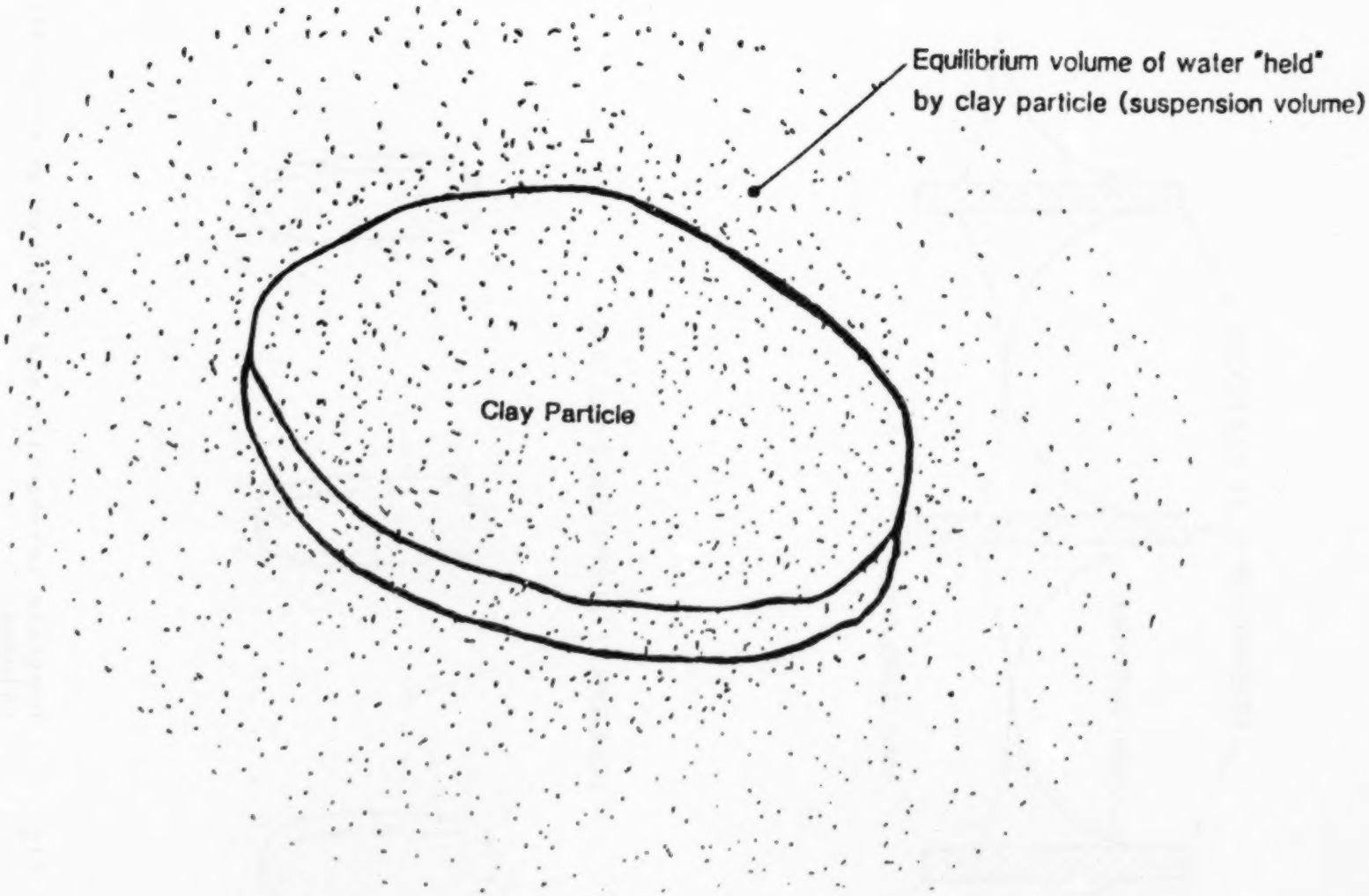
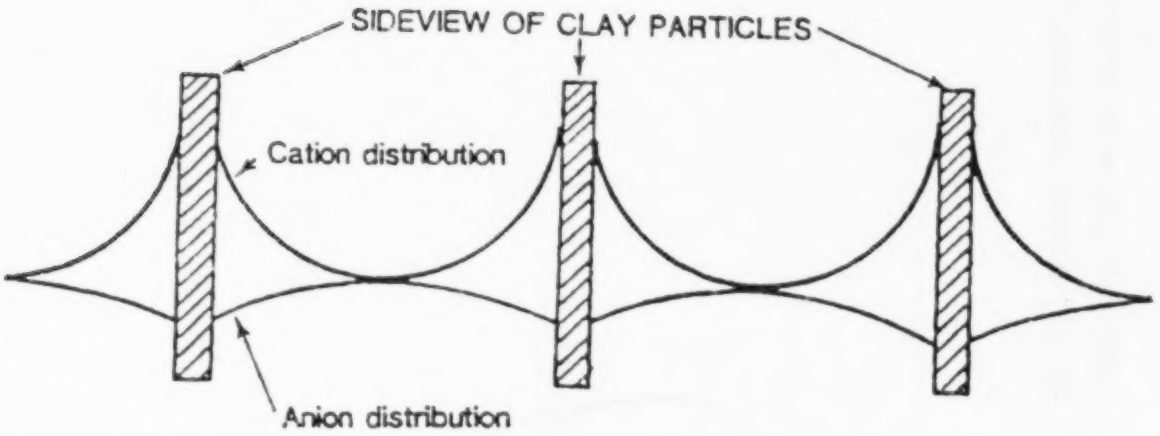


Fig. 4. Simple clay particle suspension volume.



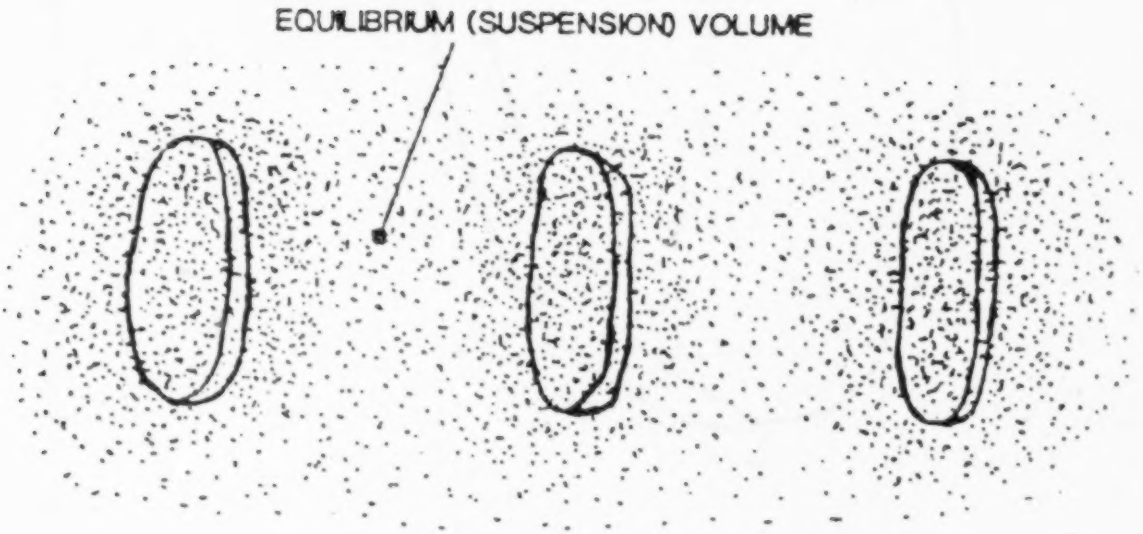


Fig. 5. Particle interaction and equilibrium suspension volumes.

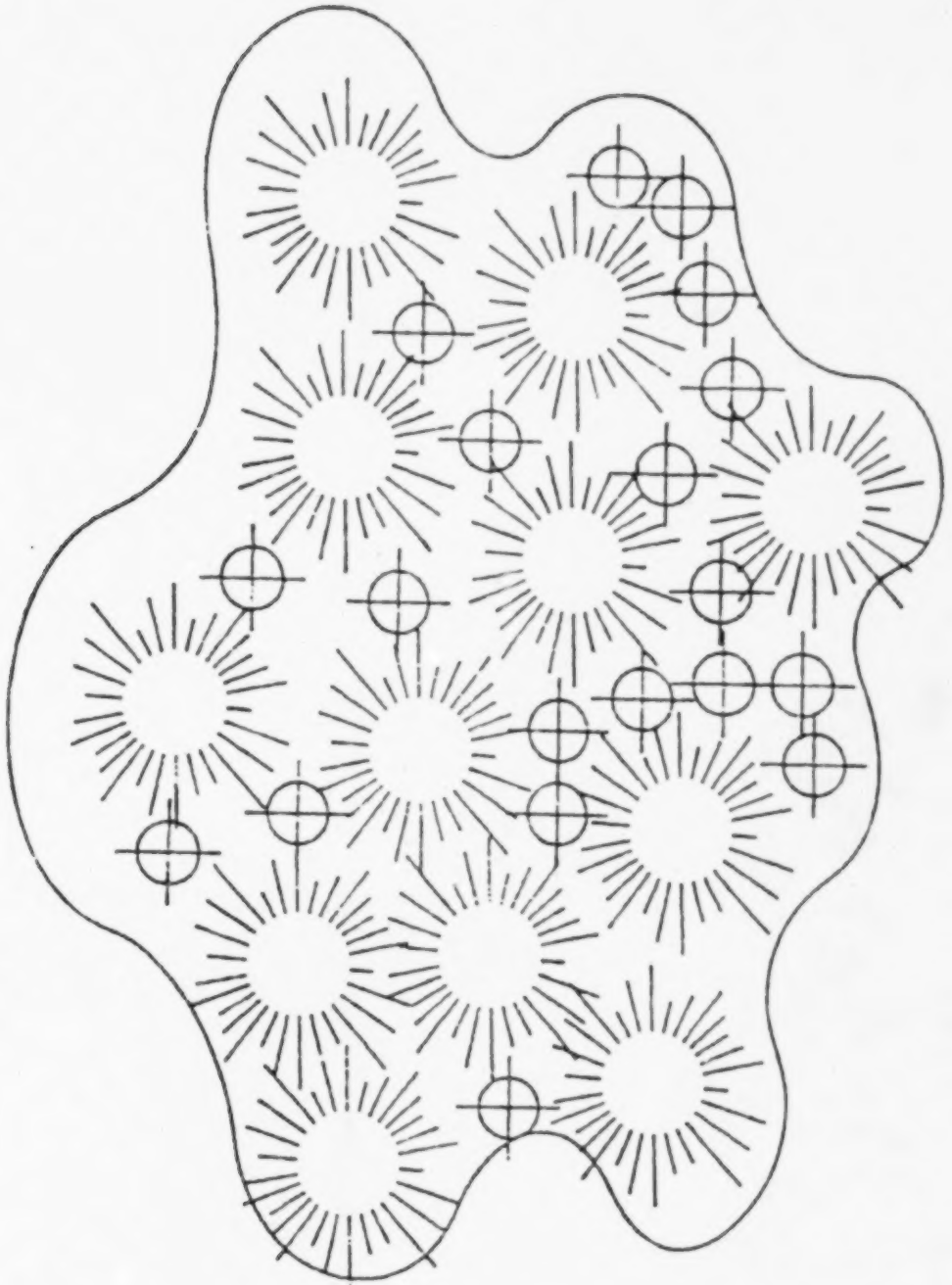


Fig. 6. Overall addition of specific constituent suspensions volumes.

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.446/6
14 August 1985

ENGLISH

Demonstration Workshop on Laboratory and
Pilot Scale Bauxite Processing

Kingston, Jamaica, 28 June - 6 July 1985

DEVELOPMENT TRENDS IN THE ALUMINA PRODUCTION*

Prepared by

János Zambó**

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DEVELOPMENT TRENDS IN THE ALUMINA PRODUCTION

AIME and ICSOBA meetings provide a good survey about the newest achievements of alumina production. The presentations on these meetings - concerning nearly every question of alumina production in detail - were published in the volumes of "Proc. of AIME Annual Meeting - Light Metals", "Alumina Until 2000. Proc. of ICSOBA Symposium, Tihany, Hungary, 1981", "Proc. of Bauxite Symp. J.Geol. Soc. of Jamaica No V. 1982" and in various "TRAVAUX" Volumes of ICSOBA. But overall studies are also not lacking (e.g. [1, 2, 3, 4] just to mention a few).

In the present paper instead of enlisting the individual results of development - attempt is made to draw up the main trends of technical progress on the basis of the analysis of the present situation and the prospects of alumina production.

The alterations in aluminium production capacities, in production and consumption figures of the past decade, further the expectable data up to the early nineties are shown in Fig.1. The same data for alumina can be seen in Fig.2. In both cases the expected increases of the production capacity figures contain only plants under construction based on literature reports.

Fig.3 is a diagram of the various cost components of alumina production and Fig.4 is a comparison of these with bauxite and alumina prices. The data of 1963 and 1975 relate to alumina plants designed in those respective years, whilst the 1985 data are average values calculated from the effective data of 16 operating plants out of which 10 are older and 6 are new ones.

Fig.5 shows the change in specific investment costs, in rates of interest and in bauxite-, alumina- and fuel-oil prices, further two construction indices, covering the same period (1963 to 1985).

The following main conclusions can be drawn from the above data:

- Over-capacities of aluminium smelters and alumina plants seem to be lasting ones. This is one of the reasons why free market prices do not cover even the production costs at many producers.
- The structure of production costs suffered a substantial change in the past 20 years. The proportion of energy costs increased in 1975 compared to 1965, while the capital cost charges reached nearly half of the total costs in newly established plants by today.
- The increase of capital costs per unit capacity was considerably more rapid than the inflation rate, but this can not be explained by the change of material prices, of construction costs, nor by the modified technical content.
- Plants under construction are preferably located together with smelters in places where abundant raw material deposits and cheap energy sources are simultaneously present.
- There is a keen competition for the exploitation of existing capacities, keeping these alive. Bauxite producers are compelled to mine their best quality bauxites to satisfy actual market demands which become more and more demanding. In case of existing plants those having lower variable costs reach a favourable position step by step, which results in the geographical rearrangement of production.

- Decisions to establish new capacities can only be expected after the reasonable utilization of existing ones. However, in order to reduce capital cost charges, the reconstruction or expansion of existing plants will have preference compared to green field establishments.

The above conclusions concerning the aluminium and alumina industries are well reflected in the area of development efforts as well. It can be stated in general that the reduction of energy consumption was in the center of technical progress during the past decade, while the main mooving force of todays' development efforts is to increase capital efficiency due to the rapid increase of capital expenses.

Increasing energy costs drew the attention to the efficiency of the process cycle and the aluminate liquor productivity in the past decade. It can be seen from the data shown, that the increase of investment good prices is similar to the oil price boom. This fact has put the increase of capital productivity in the limelight. This means that besides or instead of looking for optimum energy consumption, the optimum of capital productivity should be strived for. In the forthcoming considerations this aspect shall prevail.

The Scientific Committee of the Symposium "Alumina Production until 2000" stated as main trends of development of the Bayer technology the following: to develop an energy saving technology; to increase the role of high temperature digestion; to introduce high capacity equipment, a fully automated process and a computerized control system.

The main plant units of the Bayer process are digestion and precipitation. Let us survey these two basic units from the point of view of liquor cycle and plant productivity.

Optimum conditions of precipitation.

It could be said, that the main line of development consists of those efforts, which assure besides the high liquor yields of the European Bayer process (70-80 g/dm^3) the properties of American Bayer products. As a matter of fact in the latter case the liquor yield is only 40-50 g/dm^3, but precipitation holding times are much shorter, only 30-50 hours versus 50-90 hours of the European process. Several reviews have been published in this field (e.g. [5, 6, 7]).

Possibilities are, however, not exhausted by far. Further efforts are necessary to combine the increase of high precipitation yields with the required alumina quality. Trends of development are:

- increase of Na_2O_k concentration
- modification of the precipitation technology.

In the course of precipitation the Al_2O_3 content of the aluminate liquor changes continuously. In our previous publication [8] it was established that a certain temperature belongs to every Na_2O_k concentration and molar ratio, where the rate of precipitation is the highest. The temperature regime belonging to the highest rate can be determined here with (see Fig.6) and by implementing the same, very favourable molar ratios can be attained in synthetic aluminate liquors at various precipitation times as shown in Fig.7.

It has to be emphasized that such temperature regimes show an optimum for precipitation yields only. An optimum considering also the required grain size and properties can be a different one [9]. A similar conclusion was drawn by

Ljapunov and Davidov in respect of the optimum temperature regime in their paper of 1983 [10].

The results in plant liquors are, however, far less favourable than in synthetic ones due to the liquor impurities. There are several publications dealing with the influence of various impurities on the precipitation rate [11, 12, 13]. It can be stated in general, that the effect of inorganic impurities on the precipitation rate is similar to that of the increase of the caustic Na_2O concentration, although its extent is much less, approx. 50 %.

Liquor impurities should be removed to increase the precipitation yield. Several processes exist for this aim. The liquor causticization with burnt lime in the course of red mud washing is the most obvious solution for the regeneration of caustic Na_2O from carbonate salts. The amount of regenerable caustic is, however, limited in this process step because of the formation of $3CaO.Al_2O_3$, therefore an additional carbonate salt removal is also usually required by means of a high concentration evaporation of the liquor (in a so-called crystallizing evaporator). Examining the different possibilities and ratios of soda salt removal it can be stated that the European Bayer process allows an 8-12 % carbonate level in practive [14, 15]. It would be of interest to investigate the possibilities of reducing the carbonate content of the American Bayer liquors as one of the most promising ways of increasing its efficiency. The removal of V, P and F salts can also take place from the spent liquor [16].

Investigating organic impurities we found that the humic acids reduce the precipitation yield and cause finer grain sizes in every case. Others came to the same results. The effect and removal of organics has been investigated by several researchers [17, 18, 19]. Oxalate can be removed

from the precipitated liquor and/or the hydrate wash water, whilst the removal of other organics can be solved either by various additives (like barium aluminate, magnesium hydroxide, some organic additives, etc.) or by liquor ignition, further by calcining the carbonate salts precipitated by superconcentrating the liquor in evaporators. Our latest results show that the so-called wet oxydation of the liquor at temperatures above 200 ^{o}C gives also favourable results [20].

The precipitation technology has developed substantially in the past years in order to combine the conditions of good precipitation yields with the required physical properties of the alumina. For this aim the agglomeration technics, the multistage seeding and the necessary classification of the hydrate grains and last but not least cooling to assure the required temperature regime were introduced. Todays' batch and continuous precipitation technologies are the combination of these elements adjusted to local conditions as shown in Fig.8.

Developments in digestion

The effect of the specific volume of digestion liquor on the liquor efficiency is well known. Development of this operation is first of all related to monohydrate bauxite processing. The trend of increasing digestion temperature is determinant. The optimum temperature is nowadays usually in the range of 240-250 ^{o}C in autoclaves and 260-280 ^{o}C in tube digesters. Besides the great intensity of digestion (short retention time, low molar ratio, a yield near to theoretical) the energy consumption is also considerably reduced, furthermore great advantages originate from improving the red mud properties (settling, high density com-

pression zone, filtrability). As a result of these the Fe_2O_3 content of the pregnant liquor has decreased to 10-30 mg/l without control filtration in one of the Hungarian plants. Besides the substantial increase in capacity the amounts of Na_2O and Al_2O_3 attached to the red mud have decreased by 50 % at the same time.

The Hungarian version of the tube digestor (Fig.9), which includes the possibility of further temperature increase, is a multiple stream (3 tube) system and is characterized by the cyclical change of the slurry and digestion liquor streams in the tubes assuring thus the dissolution of the scales formed during operation. The streams are united at the final temperature of digestion and in this way the total volume of the digestion liquor works for the dissolution of the aluminium containing minerals.

The development of digestion technology brings results mainly in such plants, where the increase of digestion temperature is limited or can only be achieved by means of huge investments. The hydrothermal transformation of goethite to hematite can be realized at digestion temperatures of 220-250 ^{o}C by various additives (e.g. iron hydrogarnets) [22, 23, 24]. The main advantages of these processes versus the conventional ones using only burnt lime are the following:

The goethite-to-hematite transformation can be realized safely even in the case of bauxites with very stable goethite contents (e.g. Guinean bauxites).

The minimum temperature required for the transformation can be reduced by 20-30 ^{o}C, the retention time by 40-70 % and the burnt lime consumption by 20-30 %.

The chemical Na_2O losses can also be reduced similarly to the causticization of red mud, but in this case a lower

specific CaO consumption can be achieved, because the Fe^{3+} ions are built into the hydrogarnet structure and consequently the SiO_2 content of the latter gets higher and its Al_2O_3 content lower (Figs.10, 11).

The reduction of the specific amount of water to be evaporated is important from the point of view of both the energy consumption and the efficacy of the process cycle. This can be achieved by reducing the amount of water used for washing the red mud and the product hydrate, by avoiding miscellaneous dilutions (parazite waters) and by flash cooling the hot slurries and liquors. Over and above the known developments in equipment (filters instead of settlers, reconstruction of the settlers themselves, etc.) substantial results can be achieved by up to date flocculants, the use of which is at the same time more favourable from the point of view of accumulation of organics than that of the formerly used starch or flour [25].

The modernization of settling and red mud washing also results in the diminishing of attached caustic and alumina losses. In case of bauxites with higher SiO_2 contents the chemical Na_2O losses cause also large expenses. Reduction of these expenses justify beside the mentioned technology using additives (hydrogarnet) even the causticization of the red mud, whereby 50-60 % of the chemical Na_2O losses can be recovered at 95-100 ^{o}C by adding 3 mol CaO per mol Na_2O.

According to our newest results in a so called complex causticization process [15] the causticization of the carbonate content of the liquor, of the removed carbonate salt and that of the red mud is united into a single process. This process can be adjusted for a relatively small investment to the existing Bayer process.

To extend the limits of the Bayer process for processing medium and low grade bauxites (with high SiO_2 contents) it is possible to treat the red mud hydrothermally at a temperature of 300 ^{o}C resulting in hdyrogarnet formation. Using a caustic liquor with a molar ratio of 4.5 90-95 % of the Na_2O content and 20-25 % of the Al_2O_3 content can be recovered in a self-supporting process with a specific lime consumption as low as 2.5 kg CaO per kg regenerated Na_2O_k. The technical preconditions of the industrial realization of this process can be met by further developing the tube digestion.

Summing up it can be stated that one can not count with a significant change of the present situation in the aluminium industry and within the same in the alumina industry of the world in the near future. Excess capacities, depressed prices and the geographical rearrangement of this industry towards areas assuring more favourable production costs will stay characteristic.

The promoter of technical improvement will be more and more the better exploitation of capital goods, the increase of the efficiency of the plant. The technological possibilities, including the equipment suitable for these and the main trends of development are summarized on the basis of the abovementioned in Table 1. The importance of increasing the digestion temperature, of purifying the process liquors and of increasing the precipitation concentration is to be repeatedly emphasized.

Table 1.

MAIN TASKS OF THE TECHNICAL IMPROVEMENTS OF ALUMINA PRODUCTION

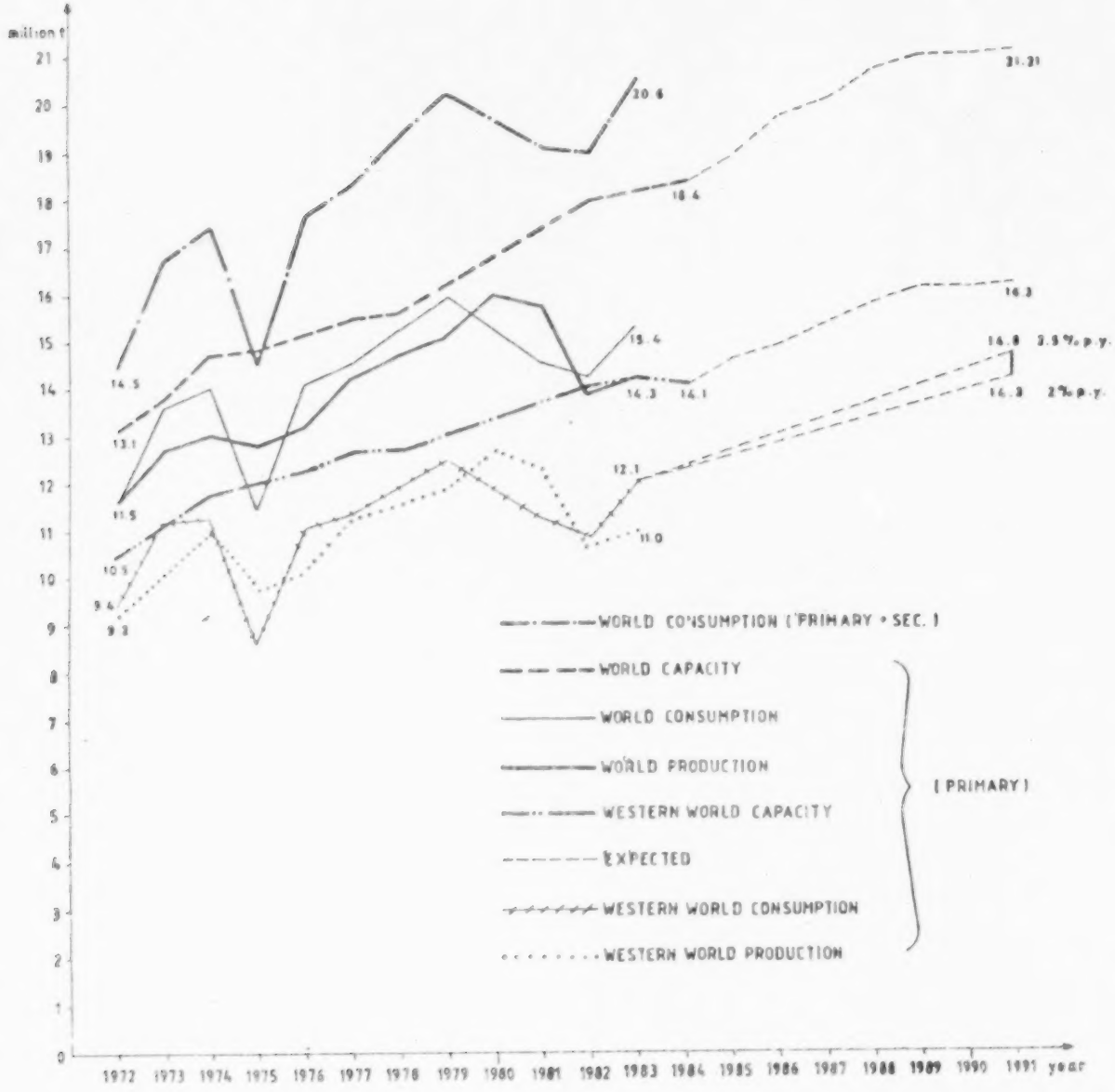
Main directions of R + D	Targets	Possible solutions
1. Improvement of efficacy of precipitation by increasing the Na_2O_k concentration of the liquor	To reach good performance in precipitation while securing requested alumina qualities	Purification of solution - removal of carbonate salts and regeneration of their Na_2O contents by . crystallizing evaporation . causticization in the washing line . complex causticization - removal of organics by . feeding magnesium salts . evaporation of hydrate wash water, oxalate separation . liquor and/or salt ignition . wet oxidation Development of technology . agglomeration . hydrate classification . multistage seeding . cooling during precipitation
2. Increasing the digestion temperature at the processing of monohydrate bauxites	To improve kinetics, to reach the theoretical yield, to conserve energy, to obtain well handable red mud	In autoclaves at 240-250 °C in tube digestor at 260-280 °C

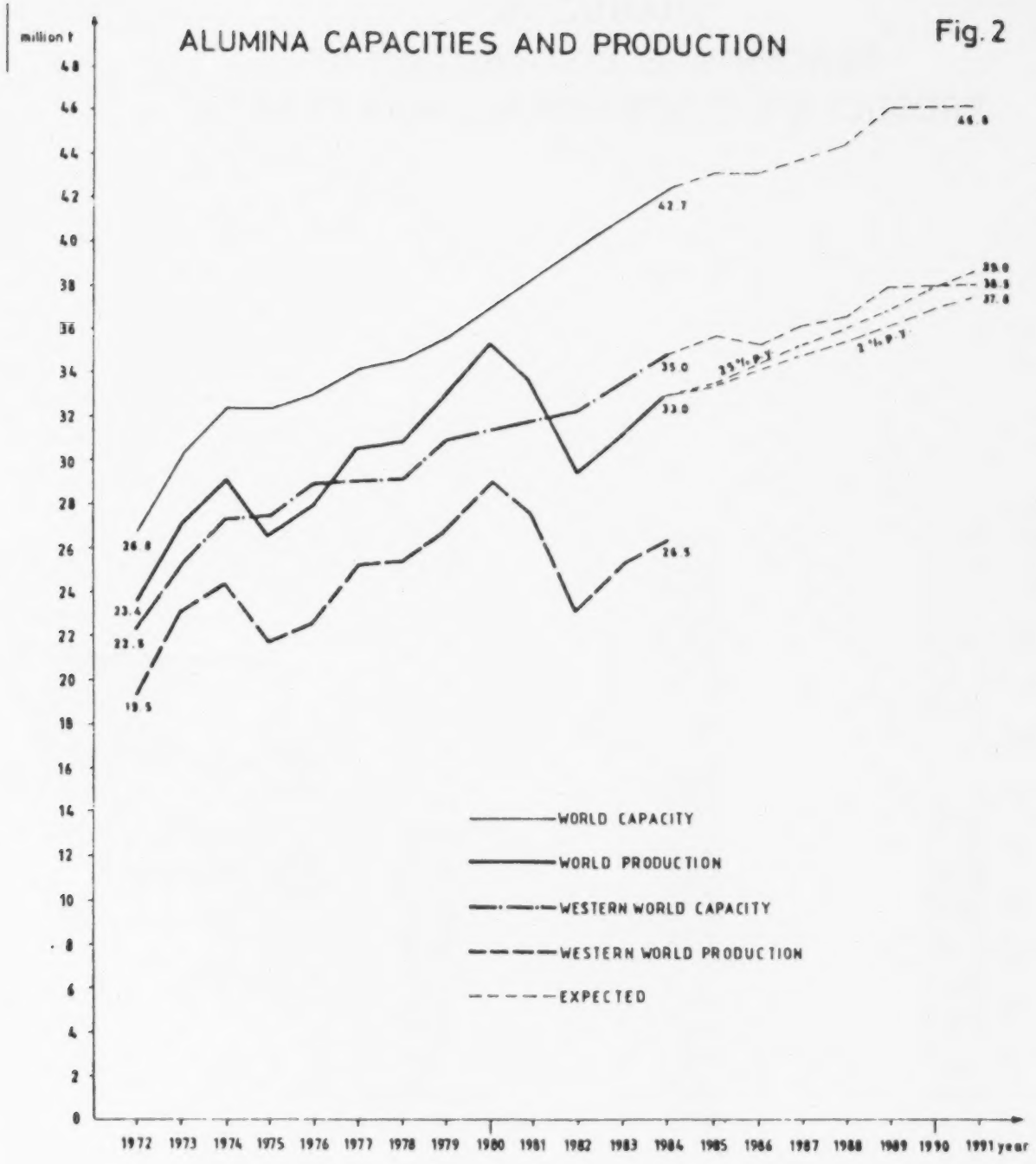
Table 1. (cont.)

Main directions of R + D	Targets	Possible solutions
3. Increasing efficacy of existing digestion lines	To release the limitations of the equipment by increasing the temperature and by modifying the technology	Technology using additives
4. Energo-technology, increase of capital productivity, optimization of the process	To minimize production costs, to increase plant productivity	Coordination of digestion and precipitation parameters and of the quantity of water to be evaporated
5. Reduction of caustic consumption	To reduce chemical and attached losses	- Carbonate salt causticization - Red mud causiticization - Complex causticization - Hydrotermal (high temperature) treatment of red mud (in case of medium and poor quality bauxites). - Modernization of red mud washing by . modification of settlers . heavy-duty filters . up to date flocculants

Fig. 1

ALUMINIUM CAPACITIES, PRODUCTION AND CONSUMPTION

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ALUMINA CAPACITIES AND PRODUCTION
Fig. 2
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2
0
46.8
42.7
35.0
33.0
26.5
26.8
23.4
22.8
19.5
1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 year
WORLD CAPACITY
WORLD PRODUCTION
WESTERN WORLD CAPACITY
WESTERN WORLD PRODUCTION
EXPECTED

Fig. 3

CHANGE IN PERCENTAGE DISTRIBUTION OF PRODUCTION COSTS FOR ALUMINA PLANTS

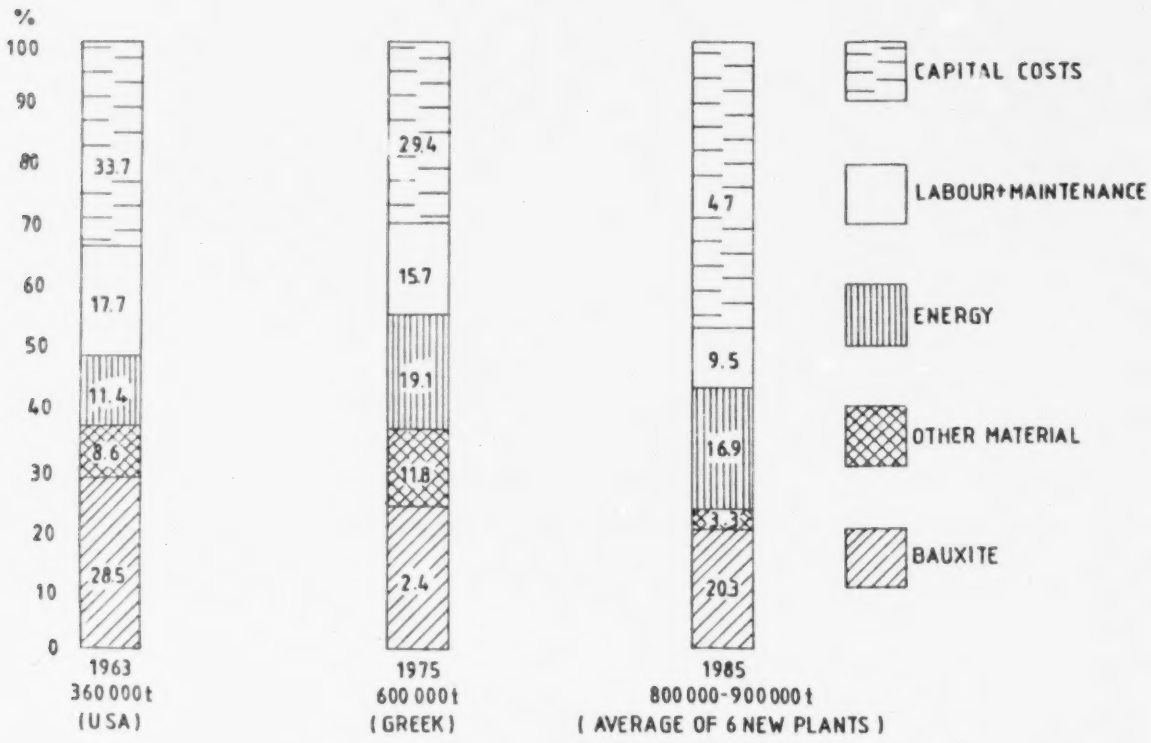


Fig. 4

CHANGE IN PRODUCTION COSTS OF ALUMINA VERSUS BAUXITE AND ALUMINA PRICES

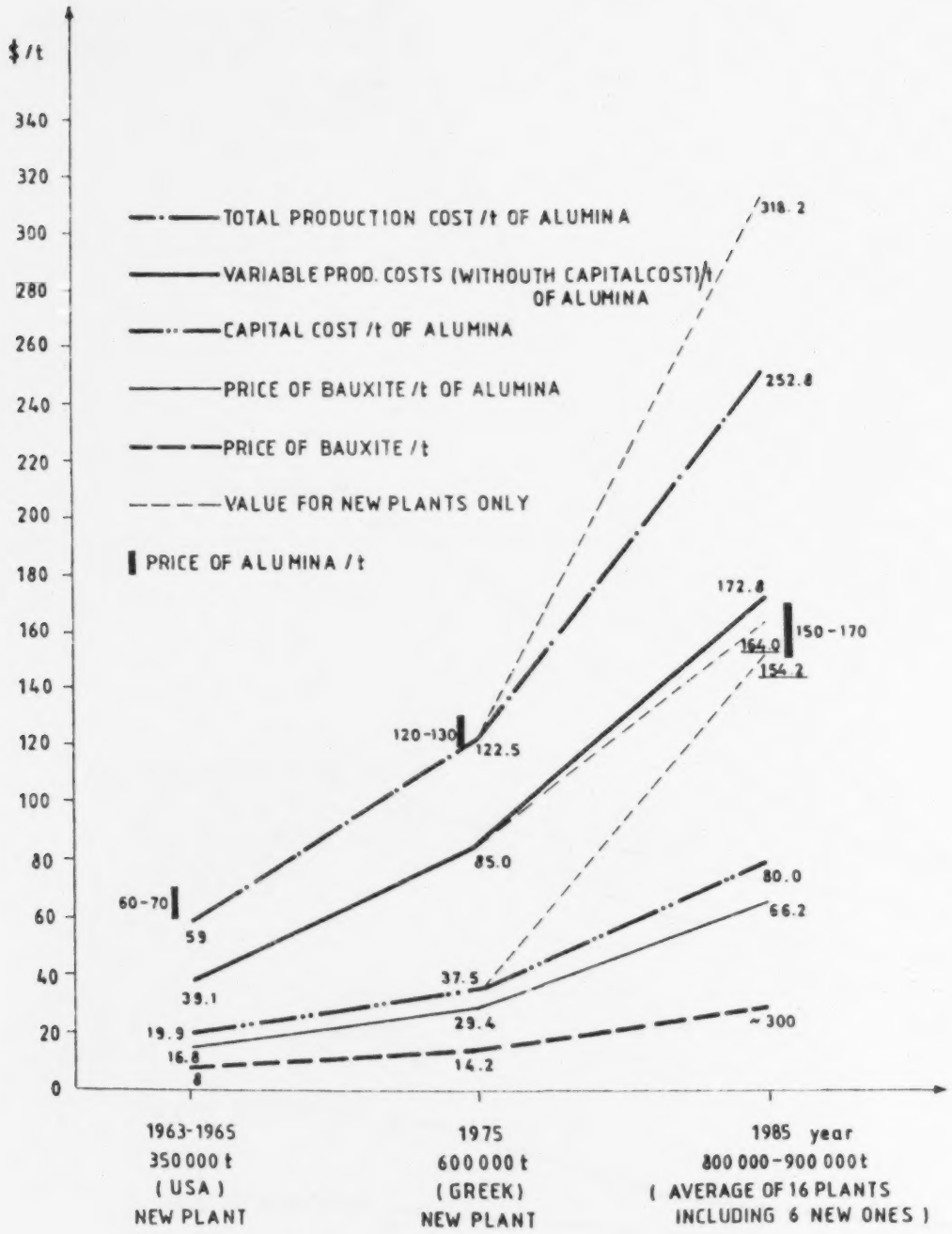


Fig.5

COMPARISON OF CHANCE OF INTERESTS, BAUXITE, ALUMINA AND FUEL PRICES, INVESTMENT COSTS OF ALUMINA PLANTS AND INVESTMENT INDICES

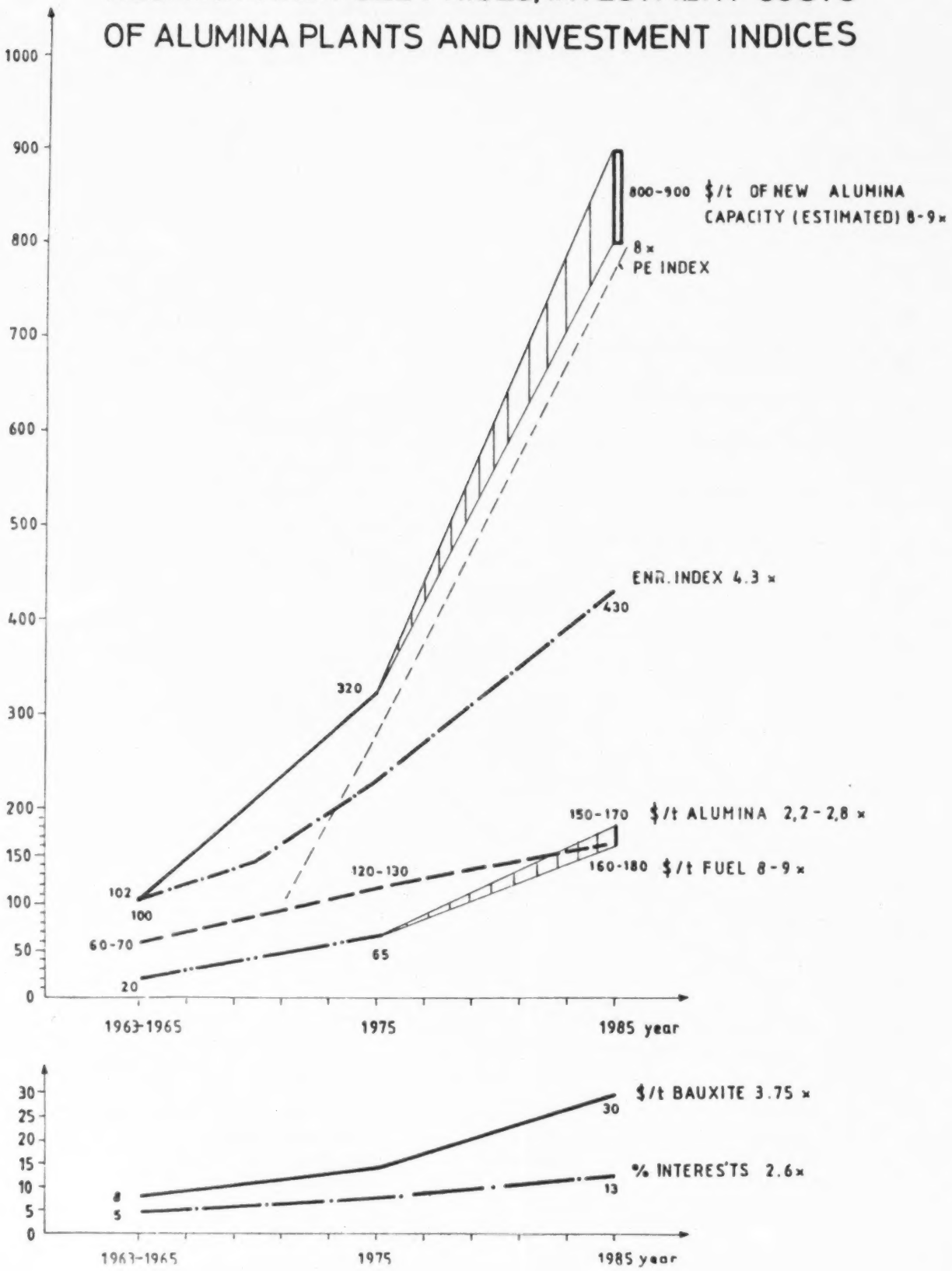


Fig. 6

TEMPERATURE CONDITIONSFOR MAXIMUM PRECIPITATION YIELD

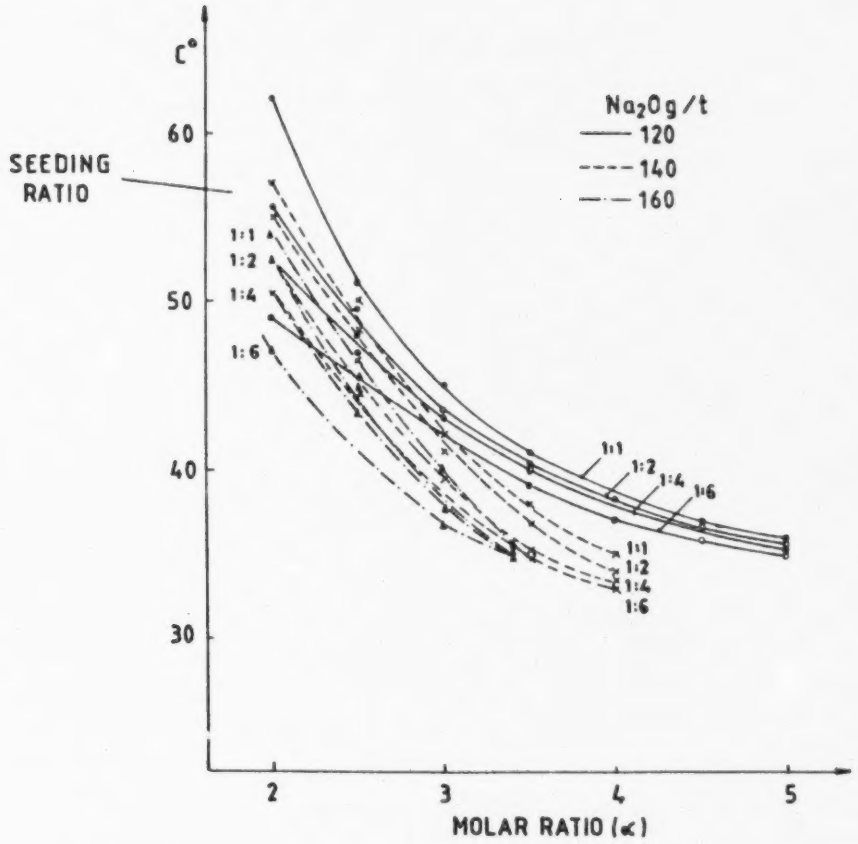
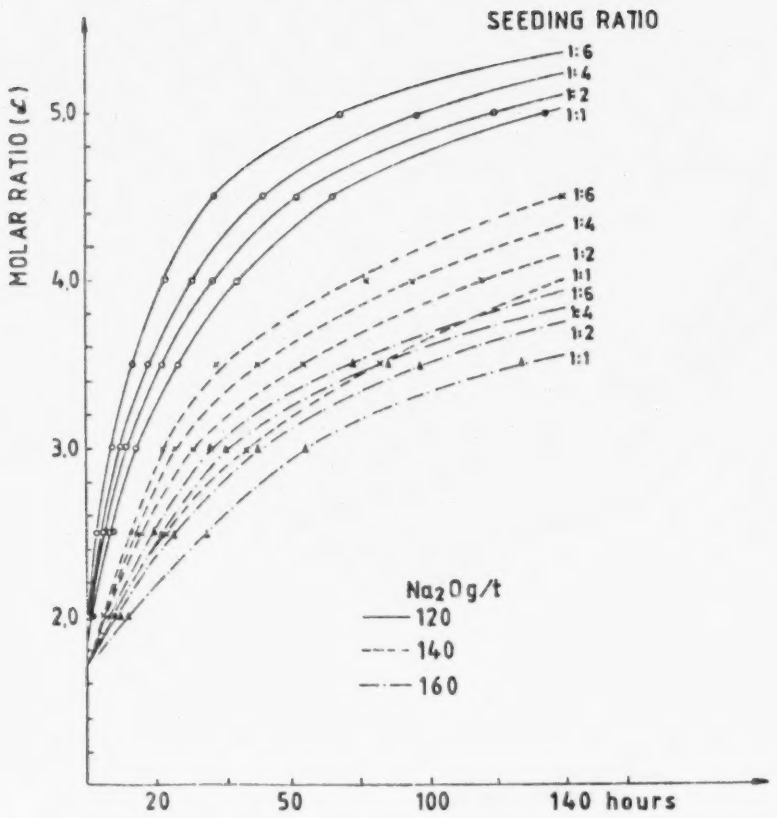


Fig. 7

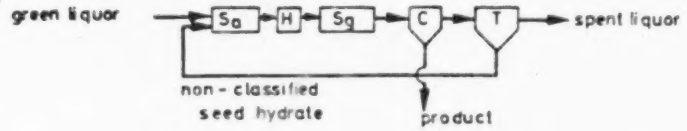
PRECIPITATION MOLAR RATIO AT OPTIMAL TEMPERATURE CONDITIONS



PRECIPITATION SYSTEMS USING AGGLOMERATION

SINGLE LINE PRECIPITATION SYSTEMS

a)



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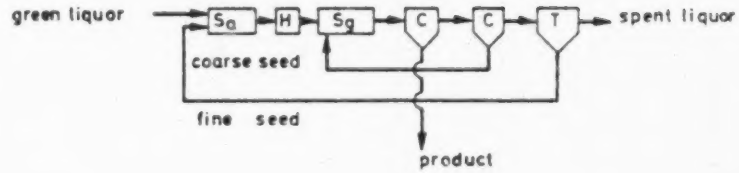

DOUBLE LINE PRECIPITATION SYSTEMS

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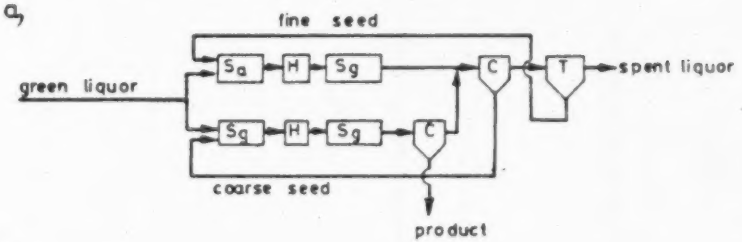

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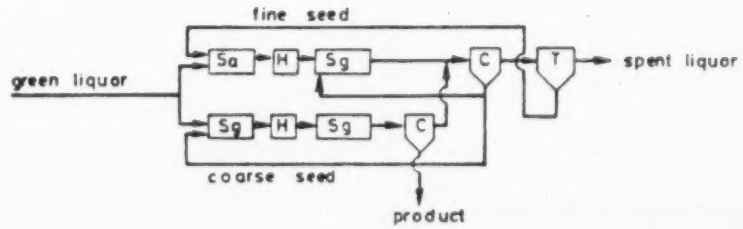
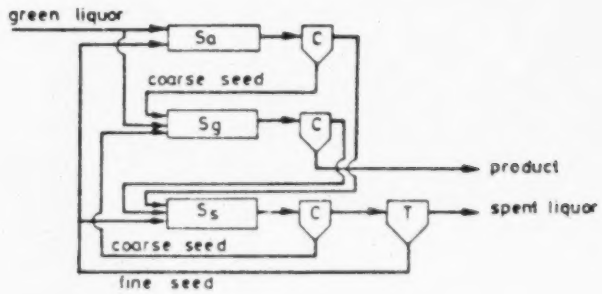
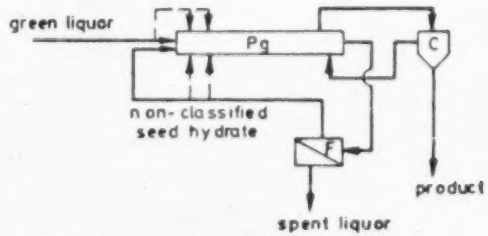


TRIPLE LINE PRECIPITATION SYSTEM /KAISER/



PRECIPITATION SYSTEM USING CRYSTAL GROWTH

(PECHINEY PROCESS)



NOTE:
- Sa agglomeration section
- Sg crystal growth section
- Ss seed generation section
- Pg crystal growth precipitation
- H heat interchange
- C classifier
- T thickener
- F filter

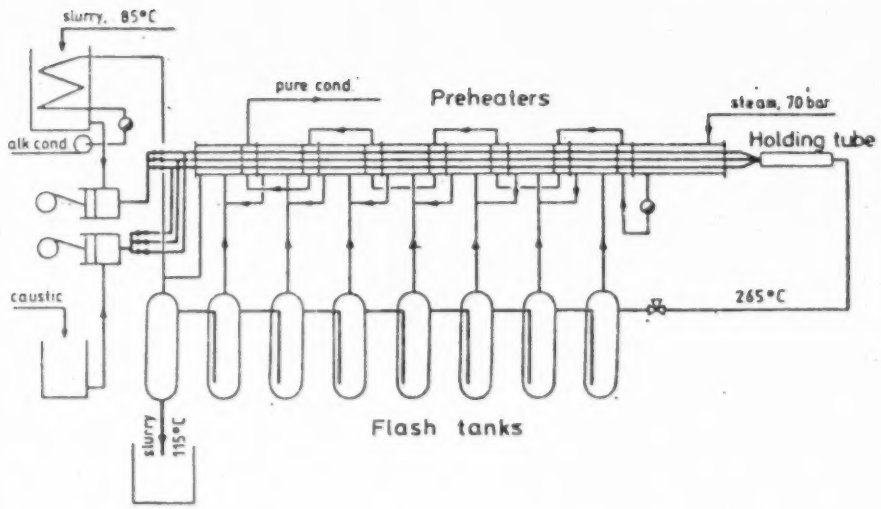


Figure 9 Tube digestion system

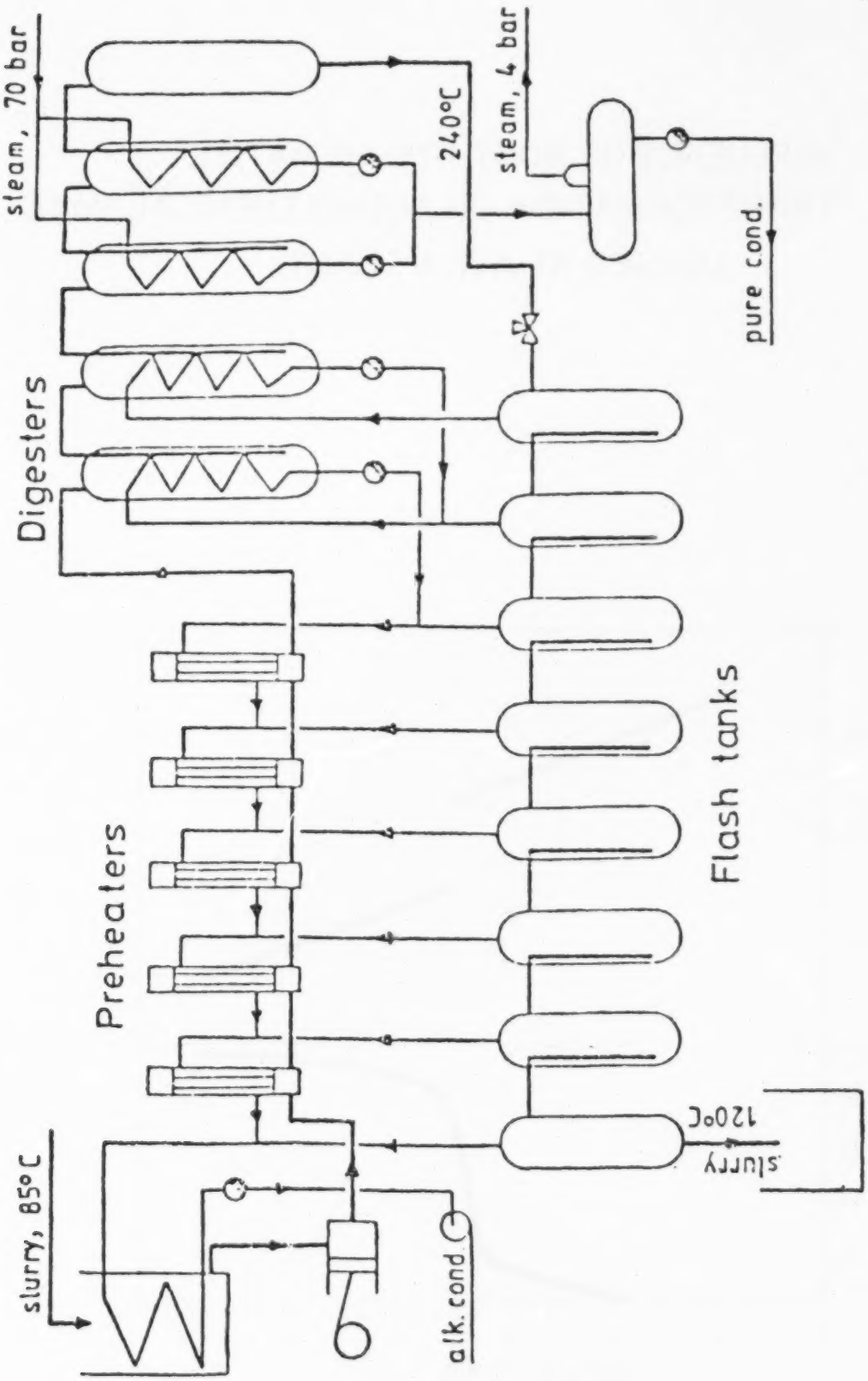


Fig. 9a. Digestion line

Fig.10

INFLUENCE OF GOETHITE-HEMATITE TRANSFORMATION ON BOUND CHEMICAL Na_2O LOSSES AT AJKA PLANT

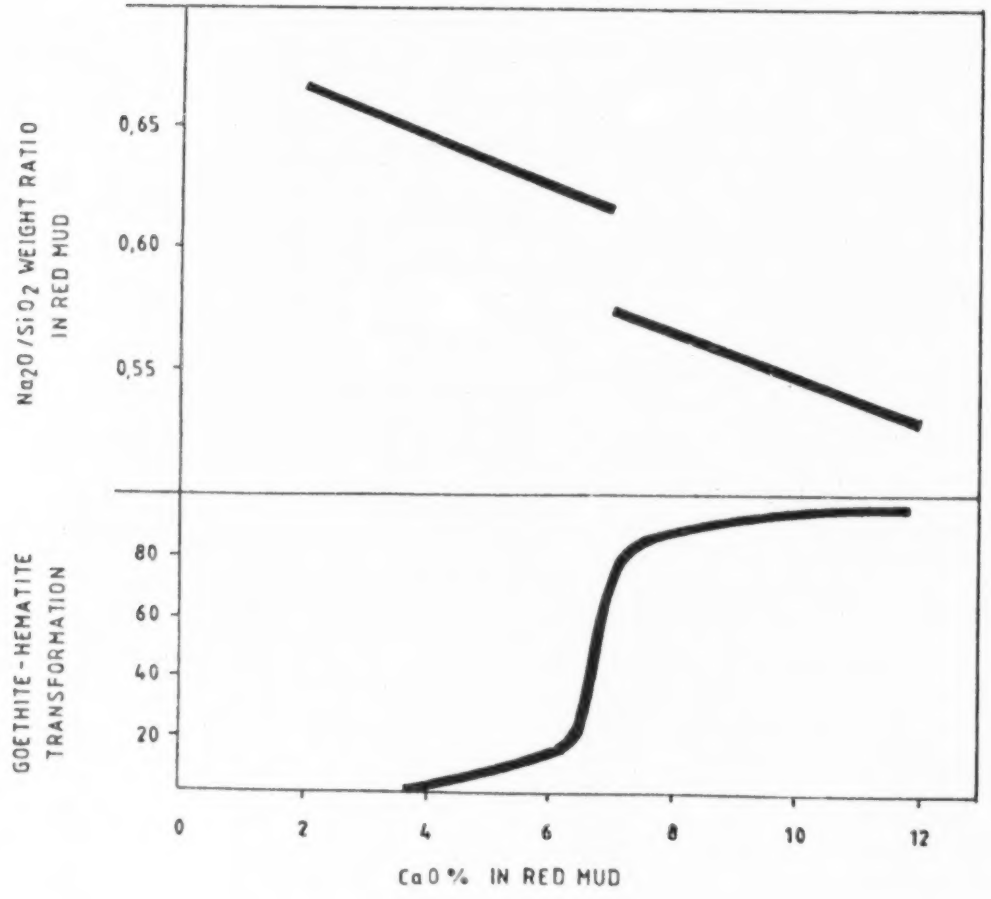
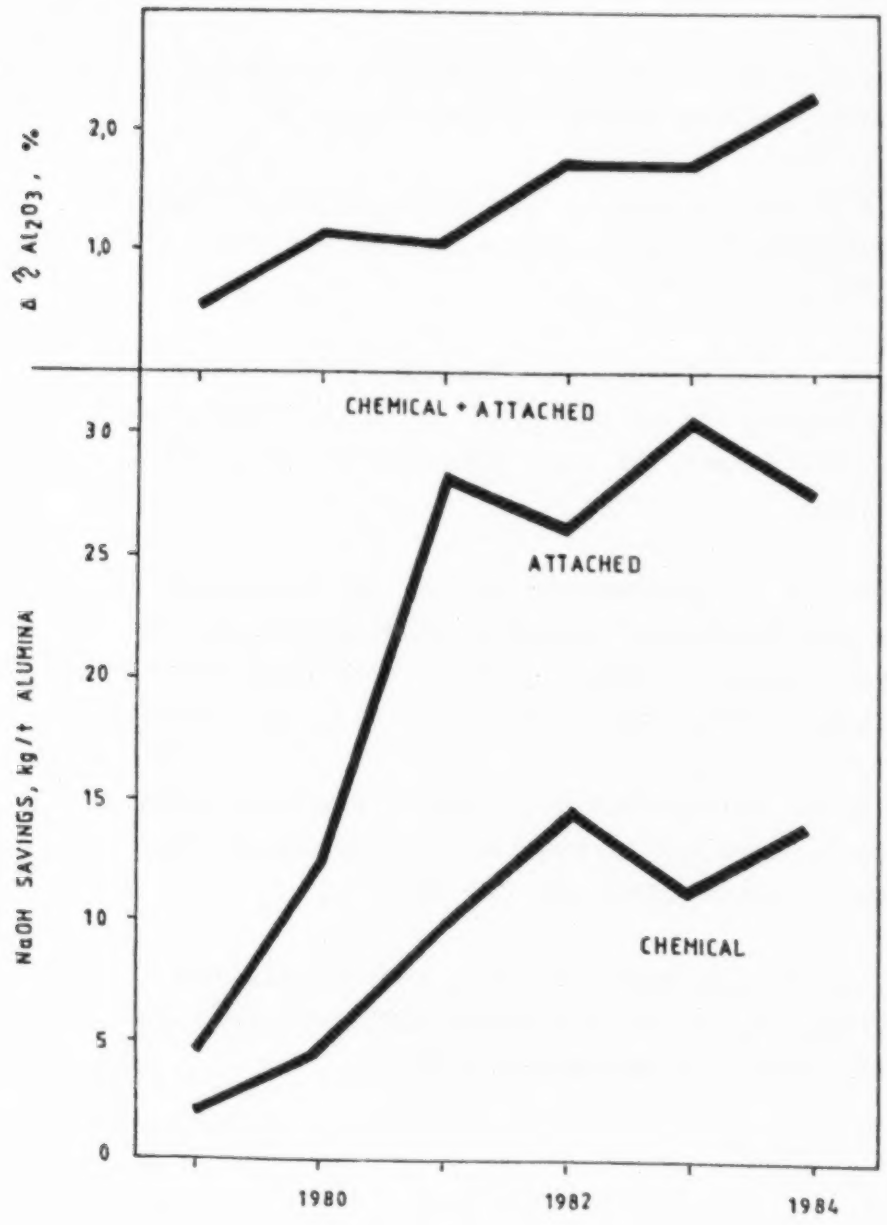


Fig.11

SAVINGS OF NaOH AND IMPROVEMENT IN YIELD BY GOETHITE - HEMATITE TRANSFORMATION AT ALMÁSFÜZITŐ PLANT



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